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Augmentation of Photovoltaic Power into Grid for Power Quality Improvement Using Unified Power Quality Conditioner (UPQC) with P&O Based MPPT

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ABSTRACT: Power Quality is one of the major concerns in the present system. Due to the rapid growth of non-linear loads, major power quality problems such as harmonics, unbalance operation and voltage deficiencies (i.e., sag and swell) arise. The above mentioned problem in the low voltage residential feeders with rooftop photovoltaic cells produces the harmonics in the system. This paper proposes PV based Unified Power Quality Conditioner (UPQC) to improve the power quality problems like voltage sag, current unbalance in the LV residential feeders which performs both the series and shunt operation. In this paper, Maximum Power Point Tracking (MPPT) algorithm is also proposed to improve the efficiency of the photovoltaic cells. The proposed algorithm composed of two parts, set point calculation and fine tuning which is based on the perturbation and observation (P&O) method. The output of MPPT is connected to the DC link of UPQC. This proposed system reduces the THD content in the source voltage and load current of the system. The performance of the proposed system is simulated using the MATLAB / SIMULINK.

KEYWORDS: Unified Power Quality Conditioner (UPQC), Photovoltaic cells, Maximum Power Point Tracking, Perturb & Observe, low voltage feeder, power quality problems.

I. INTRODUCTION

The power quality problems become a major concern of industries due to massive loss in terms of time and money. Hence, there are always demands for good power quality, which positively resulting in reduction of power quality problems like voltage sag, swell, harmonic, unbalance and flicker.The voltage unbalance is one of the most power quality problems in the low voltage residential feeder with the random location and rating of single phase rooftop photovoltaic cells. This can be eliminated using the custom power devices in the distribution feeder [1]. Among the various custom power devices unified power quality conditioner (UPQC) plays a major role in the power quality improvement. This UPQC has the advantage of both the D-STATCOM & DVR because it has both the series and shunt converters which perform the operation of the above mentioned devices [2].Voltage profile in the residential feeders can be maintained by improving the R/X ratio, controlling the phase angle and magnitude of series injected voltage using UPQC [3-5]. Voltages are well balanced at the supply side level; the voltages at the customer side can become unbalanced due to the unequal system impedances, single-phase loads or large number of single-phase transformers [6]. Nowadays, there is a growing interest in residential customers to install single-phase grid-connected rooftop Photovoltaic cells (PV) due to incentive police in several countries. Several technical problems of these systems such as harmonics, voltage profile and power losses are studied and investigated [7].

A voltage and VU sensitivity analysis is carried out in location and rating of the PVs on a LV distribution feeder. It was demonstrated that non-standard VU is more probable at feeder end compared to feeder beginning due to voltage rise and reverse power flow probability in the network as a result of high PV penetration level [8]. UPQC is used to resolve different kinds of power quality problems like reactive power compensation, interruptions and harmonics. DC link

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voltage is connected with PV module to reduce the cost [9-10].Performance of PV array and a comparative analysis is made if single and multiple arrayis connected with UPQC in order to improve the power quality problem [11-12]. Solar photovoltaic systems are used to utilize energy of sun in power generation during recent years. PV systems require maximum power point tracking technique (MPPT) techniques to maximize the energy due to non-linear PV characteristics. The most commonly used MPPT techniques are perturb and observe technique [13-14]. To mitigate the voltage unbalance issue caused by the high penetration of photovoltaic systems into the low voltage distribution networks using a single phase energy storage system [15]. In this paper, voltage unbalance can be improvement using UPQC with rooftop photovoltaiccells. In addition to this maximum power point tracking (MPPT) algorithm is proposed to improve the efficiency of the photovoltaic cells. The proposedalgorithm composed of two parts, set point calculationand fine tuning which is based on the perturbation and observation (P&O) methods.

II. UNIFIED POWER QUALITY CONDITIONER

The UPQC is the device consists of two converters, shunt and series which are connected through a common DC link capacitor. The series converter compensates for supply voltage harmonics and voltage unbalances, act as a harmonic blocking filter and damps power system oscillations. The shunt converter compensates for load current harmonics, reactive power and load current unbalances. In addition, it regulates the DC link capacitor voltage. UPQC combines the operation of both the Distribution Static Compensator (DSTATCOM) and Dynamic Voltage Restorer (DVR) together. In the voltage control mode, voltage profile can be maintained at the source end. In the current control mode, current profile can be maintained at the load end.

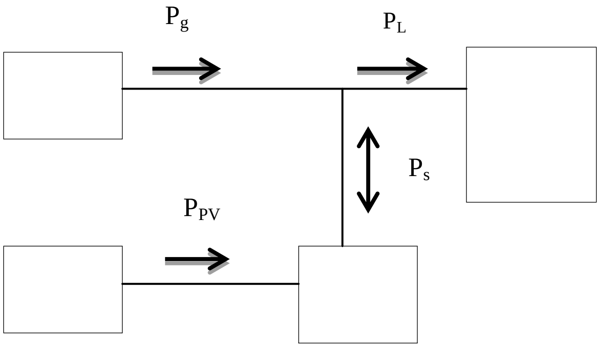

Fig.1 Block Diagram of Proposed System

Fig.1. shows the block diagram of the proposed system where UPQC is the heart of the proposed system. Becausepower quality improvement can be done using this UPQC.

III. UPQC IN POWER DISTRIBUTION SYSTEM

A UPQC compensated distribution system is shown in Fig.2. It consists of load that is supplied by a source through a feeder. The load voltage is denoted by V_l and the source voltage by Vs, the resistance Rs and feeder impedance by Ls. It is to be noted that this impedance can also be the Thevenin's impedance looking into the network from the Point of Common Coupling (PCC). In that event Vs would be the Thevenin's voltage.The voltage at the point of common coupling is denoted by the terminal voltage Vt. The idealized UPQC combines the current source if and the voltage source V_d. The purpose of the series voltage source of the UPQC is to insert voltage V_d such that the load voltage V_l is a balanced sinusoid irrespective of unbalance or distortion in the terminal voltage Vt. On the other hand, the purpose of the shunt current source is to inject current if such that the source current is Is balanced and distortion free irrespective of the shape of the load current I_l.

The UPQC must therefore provide a steady voltage to the load terminal and at the same time draw pure sine wave current from the source irrespective of unbalance or distortion in the system quantities. Furthermore, we stipulate that

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the UPQC must be controlled using the local variables only, which in this case are the terminal voltage, load and source currents.

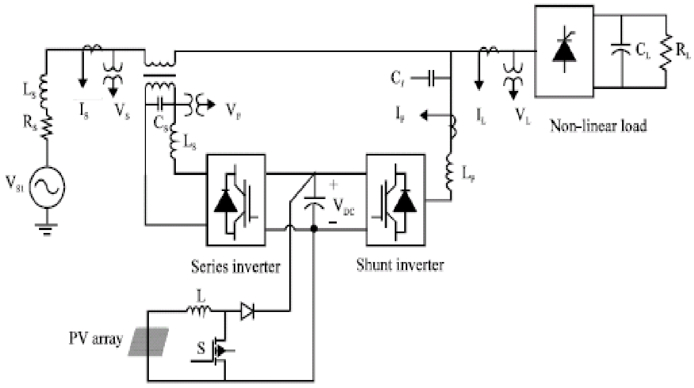

Fig.2. UPQC Compensated distribution system

IV.COMPENSATION STRATEGY OF UPQC

Consider the equivalent circuit of the UPQC.Fig.3. shows the equivalent circuit for the unified power quality conditioner.

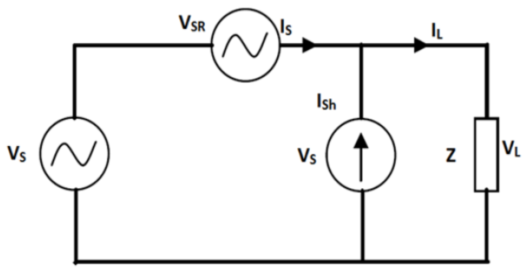

Fig.3. EquivalentCircuit of UPQC.

In this circuit,
V_S represent the voltage at power supply
V_{SR} is the series-APF for voltage compensation,
V_L represents the load voltage and
I_{Sh} is the shunt-APF for current and VSR compensation.
Due to the voltage Distortion, the system may containnegative phase sequence and harmonic components. Ingeneral, the source voltage in Figure can be expressed as:

$$V_S + V_{SR} = V_L \qquad (1)$$

To obtain a balance sinusoidal load voltage with fixedamplitude V, the output voltages of the series-APFshould be given by;

$$V_{SR} = (\mathrm{V} - \mathrm{V}_{1P}) \sin(\omega t + \theta_{1P}) - V_{Ln} - \sum_{k=2}^{\infty} V_k(t) \qquad (2)$$

where,
V_{1P}: positive sequence voltage amplitude fundamental frequency
Θ_{1P}: initial phase of voltage for positive sequence
V_{Ln}: negative sequence component

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The shunt-APF acts as a controlled current source and itsoutput components should include harmonic,reactive and negative-sequence components in order to compensatethese quantities in the load current, when the outputcurrent of shunt APF I_{sh} is kept to be equal to thecomponent of the load as given in the following equation:

$$I_L = I_{1p}\, cos(\omega t + \theta_{1P})\, sin\,\varphi + I_{Ln} + \sum_{k=2}^{\infty} I_{Lk} \quad (3)$$

$$\emptyset_{1P} = \varphi_{1P} - \theta_{1P} (4)$$

where,

φ_{1P} : initial phase of current for positive sequence

As seen from the above equations that the harmonic, reactive and negative sequence current is not flowing into the power source. Therefore, the terminal source current is harmonic free sinusoid and has the same phase angle as the phase voltage at the load terminal

$$I_S = I_L - I_{sh} (5)$$

$$= I_{1p} \sin(\omega t - \theta_{1p}) \cos \varphi_{1p} \quad (6)$$

IV. PV AND MPPT

The block diagram of the proposed PV-UPQC has been shown in Fig.1. As shown in the circuit, the PV has been connected to the dc link of the active filters through a boost converter. The PV partially provides electricity to the nonlinear load and the rest will be provided by the utility grid. The nonlinear load is of diode rectifier type. The compensation techniques for both the shunt and series active filter have been discussed in the above section. In order to improve the performance of the solar panel,PV systems need to operate in maximum power.Hence Maximum Power Point Tracking (MPPT) algorithm is implemented in this proposed system. MPPT tracksthe maximum power point where the current and voltage at which a solar module generates the maximum power. Among the various types perturb and observe (P&O) method is used which is simple, economical and easy to operate.

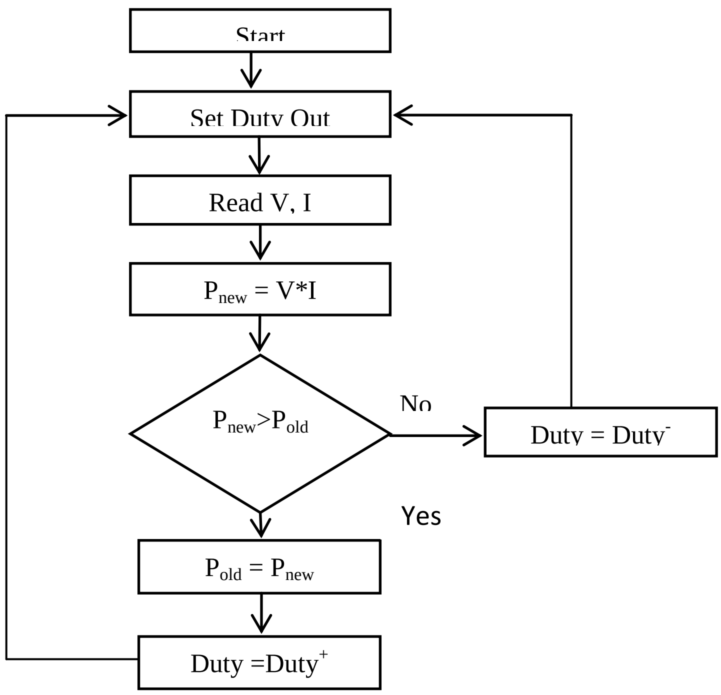

Fig.4 Flow Chart of P&O method

The P&O algorithm is also called as “hill-climbing” method. Fig.4 shows the operation of P&O method. In this method, the power (P_{new}) can be measured from the voltage and current of the solar module. This power can be compared with the existing power (P_{old}). If P_{new} is greater than the P_{old}, switching angle has to be decreased which means we have to decrement the duty cycle. On the other hand, switching angle has to be increased which means we have to increment the duty cycle. Before increasing the duty cycle, assign the newly calculated power as old power. Based on these facts, the algorithm is implemented. The process is repeated until the maximum power point is reached. Then the operating point oscillates around the MPP. This kind of observing and perturbing to reach the maximum power is known as the perturb and observe method.

V. SIMULATION RESULTS

To demonstrate the effectiveness of the proposed system, UPQC is simulated using MATLAB/SIMULINKfor the system disturbances. The results are shown for source voltage and load current.Two conditions are carried out in this system which is before and after connecting the PV-UPQC in the feeder.Fig.5 shows the PV output voltage.Fig.6 and Fig.7 shows the source voltage and load current waveforms before connecting the PV-UPQC to the feeder.

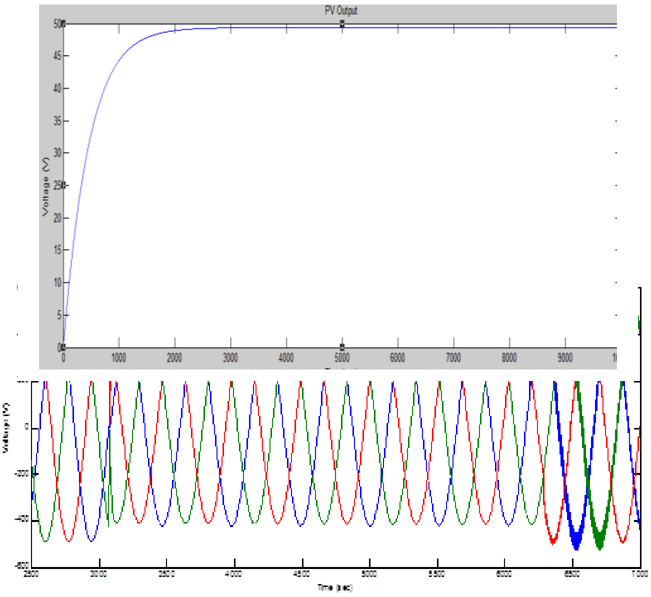

Fig.6 Source Voltage before Compensation

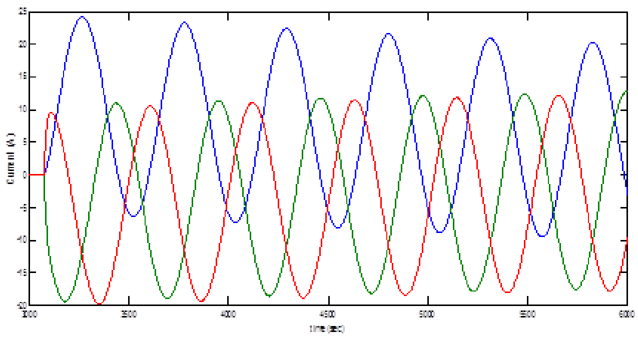

Fig.7 Load Current before Compensation

The %THD content in the source voltage and loadcurrent before compensation is shown in Fig.8 and Fig.9. Before connecting the PV-UPQC, voltages and current gets distorted which leads to greater THD values that is shown in the figures mentioned above.

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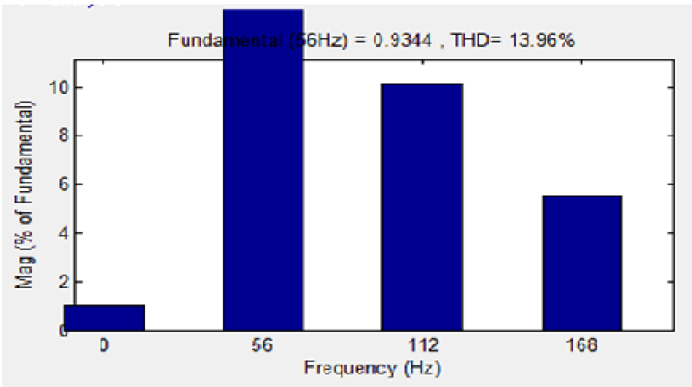

Fig.8 THD Content in the source voltage before compensation.

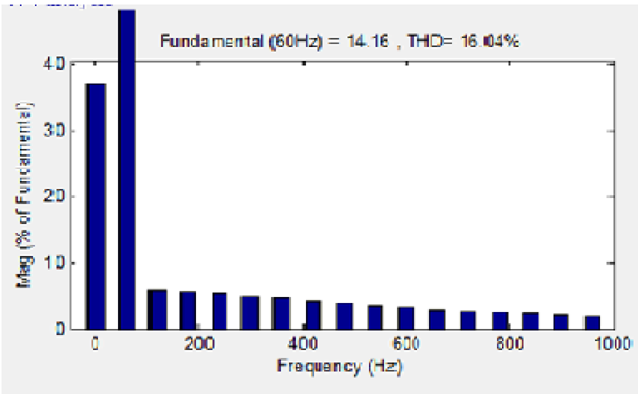

Fig.9 THD Content in the load current before compensation.

After Connecting the PV-UPQC in the feeder, the voltage and current unbalance can be improved. The voltage and current waveforms after compensation is shown in Fig.10 and Fig.11. The series injection voltage maintains the voltage profile and the shunt injection current maintains the current profile of the system.

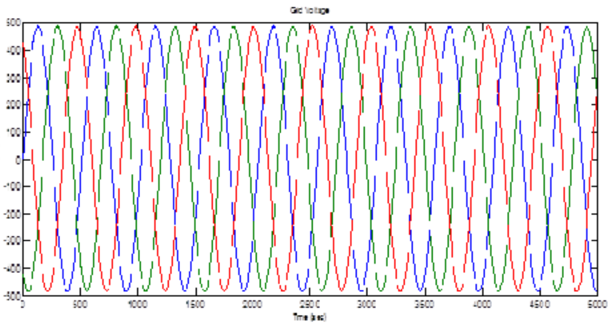

Fig.10 Source Voltage after Compensation

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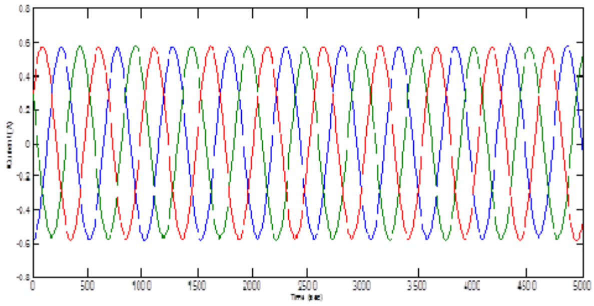

Fig.11 Load Current after Compensation

The %THD content in the source voltage and load current after compensation is shown in Fig.12 and Fig.13. After connecting the PV-UPQC, the harmonic content present in voltage and current gets reduced. THD value is shown in the figures mentioned above.

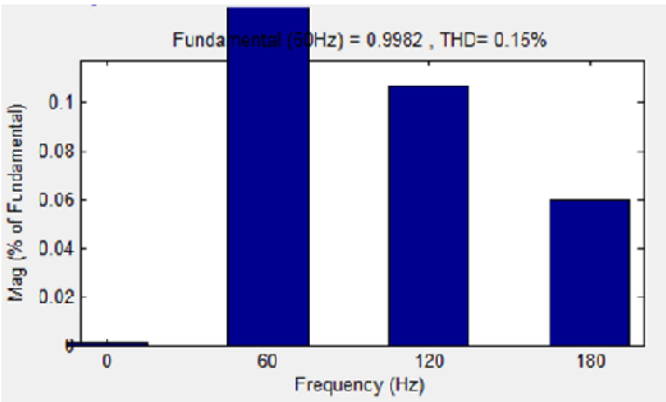

Fig.12 THD Content in the source voltage after compensation.

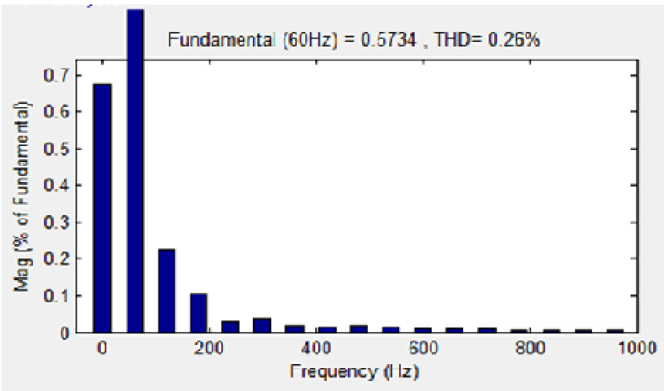

Fig.13 THD Content in the load current after compensation.

From the above waveforms it is observed that the source voltage and load currents are balanced, sinusoidal and in-phase. So the UPQC is able to compensate the unbalance in source voltage and load current. The comparison table for THD analysis is shown in the table I. Fig.14 shows the chart for THD analysis.

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TABLE I COMPARISON TABLE

% THD	Without PV-UPQC	With PV- UPQC
Voltage THD	13.96	0.15
Current THD	16.04	0.26

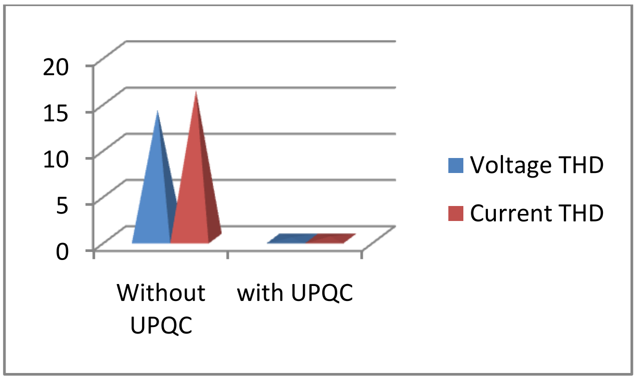

Fig.14 Chart for THD Analysis.

VII .CONCLUSION

This paper presents the design of the Unified Power Quality Conditioner with photovoltaic cells. The UPQC is configured taking right shunt topology into account. A compensation strategy has been developed. The photovoltaic cell in this system partially provides electricity to the non-linear load. To be economically efficient, photovoltaic cell should operate at the maximum power point condition. Simulation result shows the source voltage and load current waveforms before and after compensation. The result shows the improvement of voltage unbalance after connecting the PV-UPQC. The %THD content in the source voltage and load current after compensation are very less. The advantages of using this device are more reliable, cost effective and can correct the unbalance and distortion in the source voltage and load current simultaneously whereas all other device can correct either current or voltage distortion. The future work is to implement the optimization technique with UPQC.

VIII. FUTURE WORK

Distributed Generation (DG) plays an important role in the electric power system nowadays. It is widely accepted that microturbine-generation (MTG) systems are currently attracting lot of attention to meet users need in the distributed generation market. Also power quality is the major problems facing in the generating stations. In order to improve the power quality, MTG systems are modeled with UPQC and performance analyses are required. This MTG is mainly preferred for its small size, low capital cost, high efficiency, high reliability, quality power, low operation and maintenance cost.

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